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13. ABSTRACT *(Maximum 200 words)*

A metalorganic vapor phase epitaxy reactor was constructed to study the epitaxy of $B_xGa_{1-x}N$ and $B_xAl_{1-x}N$ on 6H-SiC substrates. The solubility of boron in AlN and GaN was shown experimentally to be very low, less than 3 at%. This low solubility of boron in the group III nitrides was consistent with thermodynamic arguments based on the structure of the binary compounds involved. Adding boron to GaN increased its energy band gap up to the point of two phases forming. Unfortunately, even small additions of diborane greatly reduced the growth rate (at 1000 °C) and the crystal quality of the deposits. This furnace is continuing to be used to study the epitaxy of GaN and AlN.

14. SUBJECT TERMS

gallium nitride, GaN, aluminum nitride, AlN, boron nitride, BN, metalorganic vapor phase epitaxy, MOVPE, thin films

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MOVPE REACTOR FOR DEPOSITION OF WIDE BAND GAP SEMICONDUCTORS

FINAL PROGRESS REPORT

J.H. EDGAR

APRIL 20, 2001

U.S. ARMY RESEARCH OFFICE

GRANT NUMBER DAAH04-96-10320

KANSAS STATE UNIVERSITY

Statement of the Problem Studied

A metalorganic vapor phase epitaxy (MOVPE) reactor was built to study the synthesis of boron gallium nitride ($B_xGa_{1-x}N$) and boron aluminum nitride ($B_xAl_{1-x}N$) semiconductor layers. These boron containing nitride semiconductor alloys may allow greater flexibility in independently controlling the energy band and the lattice constants than is possible with other group III elements. Several advantages may be possible. By replacing approximately 5% of the Al atoms in AlN with B ($B_{.05}Al_{.95}N$), lattice constant matching is possible with 6H-SiC; similarly, replacing 12% of the Ga atoms in GaN with B ($B_{0.12}Ga_{0.88}N$) eliminates its mismatch with AlN. This is turn may reduce the dislocation densities in these films. At low boron nitride (BN) content, these alloys may provide a superior alternative to reducing the energy band gap than the established technique of alloying GaN and AlN with indium nitride (InN), and will have greater thermal stability and smaller changes in the lattice constants leading to improved crystal quality. The effect of process conditions on the properties of the deposited films was to be established.

An additional goal was to build an MOVPE system for studying the epitaxial growth of nitride semiconductors in general. This reactor was to enhance the research competitiveness of Kansas researchers by producing materials equal to the best in the world, made with the compositions and structures of their design, to make industrial and governmental research collaboration more attractive.

Summary of the Most Important Results

The solubility of boron in $B_xGa_{1-x}N$ films deposited on 6H-SiC(0001) substrates at 1000 °C was quite low, 1.5 at % B. At higher boron concentrations, phase separation into a BGaN-rich phase and an amorphous, hexagonal BN phase occurred. For single phase $B_xGa_{1-x}N$ films, the energy band gap increased with the boron concentration. The preparation of preparing boron containing nitride semiconductors proved very difficult by MOVPE. At temperatures normally employed for successful AlN and GaN epitaxy (1050 °C and 950 °C respectively), the addition of even a small amount of diborane (B/Ga ratios greater than 0.02) reduced the growthrate by a factor of 3. In addition, the surface morphology and the crystal quality of the films degraded as the boron content increased.

A thermodynamic analysis was performed to predict the vapor-solid distribution relationship, growth efficiency, and maximum single phase solubility of $B_{1-x-y}Ga_xAl_yN$. The large structural dissimilarity between BN and both GaN and AlN make this a highly nonideal solution. The maximum predicted boron solubilities were 1.8 at% in BGaN and 2.8 at % in BAlN at 1000 °C. The growth of BGaN is controlled by the much higher Ga partial pressure than that of B over the alloy. This large difference leads to an inhomogenous distribution of elements in the alloy films.

The MOVPE reactor was employed in studies of buffer layer growth of GaN on sapphire, the effects of 6H-SiC substrate etching on subsequently grown GaN epitaxial layers, and the epitaxial growth of cubic GaN on SiC/Si(001) substrates. This research supported collaborations with other faculty at Kansas State University and Wichita State University. This reactor continues to be used by graduate students currently studying the electrical properties of AlN on 6H-SiC substrates with different pregrowth treatments.

Publications

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Reportable Inventions

None

Participating Personnel Earning Advanced Degrees

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